COARSENING UP: EXPANDING THE PARTICLE SIZE DISTRIBUTIONS OF LUNAR SIMULANTS TO ENCOMPASS A COMPREHENSIVE RANGE OF REGOLITH GRANULARITY. R. N. Kovtun[1], J. E. Gruener[2], and A. Slabic[1]. [1]Jacobs/NASA Johnson Space Center (rostislav.n.kovtun@nasa.gov), [2]NASA Johnson Space Center.

Introduction: Due to a paucity of lunar regolith samples, simulated granular materials (simulants) have been developed and deployed for a variety of engineering and research purposes in an attempt to meet the requirements for lunar exploration. Broadly speaking, these manufactured materials aim to replicate the compositional (i.e., mineralogy and chemistry) and physical (e.g., particle size distribution, particle shape) profiles of lunar soil samples collected during the Apollo missions. While creating a "near-perfect" lunar simulant is prohibitive due to the unique formative processes (i.e., meteorite impacts, solar wind implantation) and conditions (anhydrous, reducing environment and exposure to radiation on the surface over billions of years) encountered on the moon, certain granular properties of the regolith can be recreated with a high level of fidelity by leveraging contemporary technologies. A fundamental physical property and descriptor, grain size can be correlated between samples and replicated through processing; however, a holistic understanding of the particle size distribution of lunar regolith must be considered when creating analog materials. This study produces particle size distributions for Apollo 16 returned samples, incorporating the sieved out >1 cm coarse-grained fraction, in order to provide a more comprehensive characterization of surficial lunar regolith grain sizes for the development of highlands-type granular analog testing materials.

Background: The generalized particle size distribution (PSD) curve of lunar regolith (Fig. 1) has been previously constrained to encompass the <1 cm soil size fraction of surficial and subsurface Apollo samples [1]. Aggregated from a variety of sources, with approximately 90% of the grain size data coming from the compilation completed by [2], the distribution curve does not include the pebble-sized rock fraction of the regolith samples that was sieved out by the Lunar Sample Laboratory Facility at NASA JSC as part of the lunar sample curation process. The separation and cataloging of samples into a finer (i.e., <1 cm – soil) and coarser (>1 cm – e.g., unconsolidated regolith, polymict breccia, cataclastic anorthosite, etc.) size fraction has led to confusion on how to bound the physical characteristic of the lunar regolith, both for simulant manufacturing and engineering testing and modeling purposes.

Initial interpretations of bulk PSD data showed that upwards of 80-90% of the lunar regolith consisted of grains less than 1 mm, leading to the creation of a somewhat arbitrary size threshold that has since permeated simulant production [3]. Along with the definition of the finer fraction (< 1 cm) of the unconsolidated surficial material as lunar soil [3], inceptive characterizations of regolith grain size distributions for the purpose of simulant manufacturing proved to be constraining and were misaligned with preexisting terrestrial soil classification schemes (e.g., British Standards Institution, International Society of Soil Sciences, US Department of Agriculture).

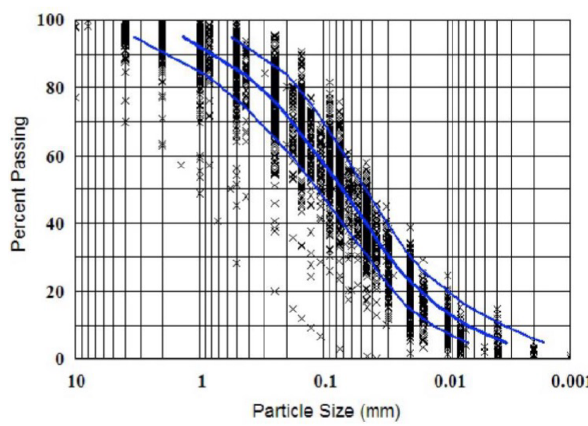

Figure 1: Lunar soil particle size distribution (middle curve) with ± 1 standard deviations (left/right-hand curves; Carrier, 2003).

Approach: Utilizing the Lunar Soils Grain Size Catalog [2], in combination with the Handbook of Lunar Soils [4] and NASA JSC ARES Lunar Sample and Photo Catalog [5], this study has produced a composite, lunar highlands-specific particle size distribution based on 25 surficial Apollo 16 regolith samples (Fig. 2). The designated datapoints were selected for their compositional congruity with the surface materials anticipated to be encountered at the Lunar South Pole, the focal point of near-future Artemis missions. Additionally, this dataset solely reflects surface samples as a means to disentangle potential noise in trends between surficial, near-surface, and sub-surface samples.

Tabulated sieve data (wt% by sieve size in microns) of the down selected surface samples was taken from the Lunar Soils Grain Size Catalog [2].

Generally, this catalog contains cumulative PSD data for samples up to 1 cm in size and does not contain information on the overall mass of the sample and associated subsamples. For this purpose, the Handbook of Lunar Soils [4] and NASA JSC ARES Lunar Sample and Photo Catalog [5] were referenced to determine the mass of each sample, both cumulatively and based on the grain size range that each associated subsample represented. For example, soil sample 61500 encompasses generic subsamples 61501 (466.9g at <1 mm), 61502 (27.43g at 1-2 mm), 61503 (20.8g at 2-4 mm), 61504 (12.70g at 4-10 mm), 61505 (1.65 at >1 cm) and a self-titled bulk reserve subsample (267.8g).

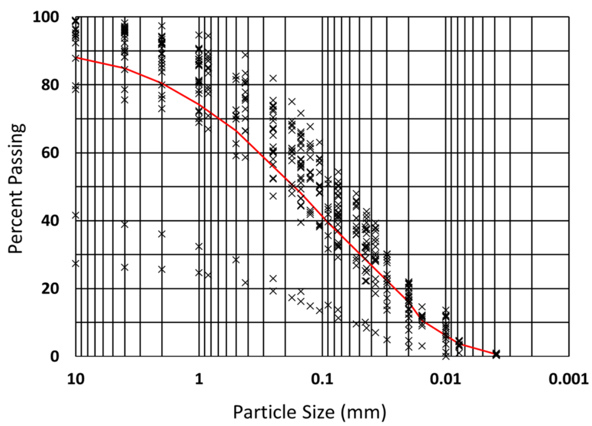

Figure 2: Apollo 16 surface sample particle size distribution with red curve as the average distribution. Data from [3,4].

The accumulated subsample masses by size fraction that were missing from [1,2] as a result of curatorial processing were back added to previously tabulated sieve data (wt% by sieve size in microns in [2]) to produce new comprehensive PSDs (Fig. 2). A qualitative check was performed on the relativeness of the back added PSD datapoints by reviewing the context under which the pertinent samples were sampled, processed, and catalogued. Furthermore, in order to create an upper limit particle size threshold for the dataset, a careful review of photographs and measurements of the coarse fraction (i.e., rocks, pebbles < 1cm) was required. Figure 2 was created in the same format as Figure 1 to highlight the differences between the datasets; however, as is apparent in Figure 2 and from the back added data, the particle size limit of the new PSD exceeds the 10 mm limit of the graph.

Conclusions: Existing particle size distribution data for lunar regolith samples does not adequately capture the coarse fraction of the granular medium. Compared to existing PSD profiles, this study produces significantly coarser shift of the average particle size when pre-sieved subsamples masses are back added to existing tabulated sieve data (wt% by sieve size in microns in [2]) of Apollo 16 surface samples. This holistic approach to understanding the range of particle sizes is integral in the manufacturing and production of high-fidelity lunar simulants for a variety of analog testing needs.

References:

[1] Carrier D.W III (2003) J. Geotech. Geoenviron. Eng., 2003, 129(10): 956-959. [2] Graf J.C. (1993) *NASA Reference Publication 1265* [3] McKay D.S. and Blacic J.D. (1989) *LPI Technical Report 91-01*. [4] Author I. J. (2002) *LPS XXXIII,* Abstract #1402. [5] https://curator.jsc.nasa.gov/lunar/samplecatalog